Translation of Appropriateness Criteria into Practice Guidelines: Application of Decision Table Techniques to the RAND Criteria for Coronary Artery Bypass Graft

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ABSTRACT

The process of creating clinical practice guidelines from collected evidence has not been well defined. We have developed a technique for translation of a comprehensive set of appropriateness criteria into a usable set of practice guidelines. The criteria are derived from a formal consensus process conducted by RAND and relate to indications for coronary artery bypass graft in acute myocardial infarction. The clinical indications defined by the expert panel are entered as conditions in a decision table. For each combination of relevant clinical findings, the recommended action is defined from the median ranking of the Rand panel. The fully constructed table is next compacted by conventional decision table techniques and sorted to facilitate parsing the knowledge. Ultimately, 8 narrative statements are derived from 51 rules. Augmented decision tables permit display of detailed data in the summary table and its access on an as-needed basis.

The development and dissemination of clinical practice guidelines represents a major health policy initiative in North America and Europe [1-3]. Methodologies are currently being developed to translate medical knowledge and expert opinion into operational recommendations that can guide clinical practice [4, 5]. Assembling the evidence to provide support for guidelines recommendations has been accomplished both by rigorous mathematical analysis of published studies and by meticulous assessment of expert judgment. However, less attention has been paid to the process of translating the accumulated evidence into useful and usable guidelines. Whatever method is used to collect the evidence, it is crucial that guidelines comprehensively address all logical possibilities of situations that may confront caregivers and that they present their recommendations in an accessible manner.

One major knowledge acquisition approach, which was devised by RAND (Santa Monica, California) and has been used for nearly a decade, results in the creation of a comprehensive set of appropriateness criteria [6]. Unfortunately, the very exhaustiveness of these criteria makes them difficult to apply in clinical practice. For example, the RAND report on coronary artery bypass graft (CABG) rates 2,989 different combinations of clinical findings [7]. In any report of this complexity, it is not surprising to find that relationships among the decision variables are obscured by the mass of data.

Having successfully applied decision table techniques to the simplification of other clinical guidelines [8, 9], we sought to convert the RAND appropriateness criteria for CABG into usable guidelines by applying decision table techniques. Our goal was to reduce an unwieldy number of clinical indications to a more manageable number and to display their content in a compact narrative format. In this paper, we describe the translation of the section of the RAND report that relates to appropriateness of CABG in the setting of acute myocardial infarction.

METHODS

RAND Methodology

RAND's formal consensus technique has been applied to a number of medical procedures, including coronary angiography, carotid endarterectomy, hysterectomy, and coronary artery bypass graft. After a literature review, each member of a panel of experts independently rates the appropriateness of a procedure on a scale of 1 to 9, where 1 indicates extremely inappropriate and 9 extremely appropriate. *Appropriate* is defined to mean that "the expected health benefit exceeds the expected negative consequences by a sufficiently wide margin to make the procedure worth doing, exclusive of cost considerations" [7].

The panelists meet to review and discuss the initial ratings and are provided with individual summaries that indicate their initial scores as well as the summary scores. After discussion a second round of ratings is performed confidentially. The final report displays the number of panelists who choose each ordinal rank, the median rank, the mean absolute deviation from the median, and an indication of the experts' agreement or disagreement for each indication.

For coronary artery bypass graft (CABG), a 9-member panel of experts was chosen from nationally recognized leaders nominated by medical specialty societies based on clinical expertise, community influence, and diversity of geographic location. Panelists

0195-4210/92/$5.00

represented internal medicine, invasive cardiology, non-invasive cardiology, and cardiothoracic surgery.

Using the literature review as a guide, indications for CABG were identified in nine clinical circumstances, including chronic stable angina, unstable angina, asymptomatic coronary artery disease, and acute myocardial infarction. Each indication represents a combination of clinical and laboratory features that distinguishes among patients who may be candidates for CABG.

Decision Tables

Decision tables have been used for decades to facilitate systems analysis and programming [10]. A decision table is a high-level knowledge representation that can be used to map combinations of clinical state variables onto appropriate action categories. Decision table manipulations can be used to ensure the logical integrity of a rule set and to optimize that rule set.

The conventional representation for a decision table is a four-quadrant matrix. The *condition stub,* located in the upper left quadrant, is a listing of the conditions (rule antecedents) that must be tested to reach a diagnostic or therapeutic conclusion. The *condition entry* quadrant at the upper right defines the value or state of each of these conditions. The *modulus* of a condition is the number of values it can assume. The *action stub* in the lower left quadrant lists all the diagnostic and therapeutic actions (rule consequents) that may be undertaken. The *action entry* quadrant in the lower right indicates the appropriate actions to be taken, given the specific condition value combinations of the condition entries above.

Each entry column represents a rule in the form "IF <condition entries> THEN <action entries>". In this rule an implicit AND binds all of the condition entries. *Dash* entries in a table indicate that a test is irrelevant to the satisfaction of a given rule.

Reduction and Decomposition of Decision Table Rule Sets

The number of rules required to completely characterize a domain can be reduced by elimination of any rules that involve testing of irrelevant variables. To find candidate rules for elimination, a decision table is examined to identify rules that result in the same action and differ at only one condition. If the modulus of the variant condition is two (i.e., the test outcome is binary) then the two rules are identical except that one contains the variant condition and the other contains its negation. The variant condition must be irrelevant since either its presence or absence results in the same action. One of the rules may be deleted from the table and the remaining rule should have a dash inserted in the entry for the variant condition. The dash indicates the irrelevance of the variant condition to the satisfaction of the rule. When the modulus of the variant condition is greater than two, the number of rules indicated by the modulus must be combined.

Each column that contains dash entries is called a *complex rule*. A complex rule actually represents a number of rules since each dashed value could be replaced by any value of the dashed condition. The *column count* of a complex rule is equal to the product of the moduli of all the dash entries in the column. For a simple rule, the column count is 1.

Hurley has described a method for decomposition of a decision table that allows it to be transformed into a more easily understood and manipulated knowledge structure [11]. The transformation requires sorting both the rows and columns of the table. The *weighted dash count* (WDC) serves as a primary key for sorting the decision table's condition rows.The WDC of a condition is a measure of the irrelevance of that condition to decision-making. The WDC is calculated for each row by adding the column counts of all the columns whose entries in that row contain dashes. If the WDCs of two or more rows are identical, the row *delta* can be used as a secondary sorting key. The delta is calculated for each row by counting the number of entries for each explicit (non-dash) value in the row. The delta is the absolute value of the difference between the highest count and the sum of all the other counts.

The first step in decomposition is to sort the rows so that those with the lowest WDCs are in the topmost positions. In the case of identical row WDCs, the delta is likewise used to sort from lowest to highest from the top down.

After the rows have been sorted, the columns are rearranged so that all rules that contain the same condition entry value for row 1 are brought together. Next, all the columns that share the same value for condition 1 are sorted to bring together those with the same value of condition 2. The procedure is continued until all the rows have been visited. This sort leaves the columns arranged in an order that is equivalent to a decision tree [8]. In this tree, each node is equivalent to the row stub and the branches represent the condition entry values.

We have developed software that automates row and column sorting as well as completeness and ambiguity checking. KADET (Knowledge in Augmented DEcision Tables) performs these manipulations on decision tables and supports an augmented decision table architecture [8].

RESULTS

The RAND ratings of appropriateness for CABG in the context of acute myocardial infarction include 207 combinations of clinical findings. Of these 207 indications, 69 relate to the appropriateness of CABG when percutaneous transluminal coronary angioplasty (PTCA) is not considered to be an option. This paper is limited to a consideration of this situation, although the same approach can be taken to evaluate the

Condition Variable	Modulus	Possible Values (Abbreviations)
Clinical status	3	Cardiogenic shock (SHK); Evolving infarction with continuing pain (PAIN); Evolving infarction - asymptomatic (N PN)
Anatomic distribution of disease	6	Left main (LM); Three vessel (3V); 2-vessels including proximal left anterior descending (2V+P); 2-vessel without PLAD involvement (2V-P); 1 vessel-PLAD (PLAD); Single vessel except PLAD (1V-P)
Ejection Fraction	3	Normal, i.e., >35% (NL); Reduced, i.e., 15–35% (RED); Low, i.e., <15% (LOW)
Risk	3	Normal or low risk (LO); Moderately high risk (MOD); Very high risk (HI)

Table 1. Relevant variables and values for decision-making regarding appropriateness of CABG in acute myocardial infarction.

appropriateness of CABG when PTCA is an option and likewise the appropriateness of PTCA alone.

Four variables were identified by the expert panelists to be relevant to the decision regarding appropriateness of CABG in acute myocardial infarction: clinical status, anatomic abnormality, ejection fraction, and surgical risk. Possible values for each of these variables as defined by the RAND panels are shown in Table 1. Each of the variables is entered as a condition in the condition stub of a decision table.

Each combination of variables described in the report is represented by a column of condition entry values. Some mathematically possible combinations are not specified in the report. In this case, a dash is entered in the appropriate cells to show that any value of the variable would not change the recommended action. For example, the panel found that CABG is inappropriate for asymptomatic patients, regardless of the ejection fraction. In this case, ejection fraction is an irrelevant condition variable.

Decision table actions are here defined as "CABG appropriate", "CABG inappropriate", and "CABG uncertain". For each clinical indication, the median rating of the consensus panel determines the action assigned in the decision table. When the rating is 1, 2, or 3 CABG is inappropriate. When the median is 4, 5, or 6 CABG appropriateness is uncertain. When the median rating is 7, 8, or 9 CABG is appropriate.

Once the RAND data has been entered into a decision table, it can be checked for completeness and consistency. No two columns of condition entries are identical. The product of the moduli of the conditions is 162 (3x6x3x3) and the sum of the column counts is also 162 thus indicating that the rule set is comprehensive and unambiguous [10].

Automated reduction is next applied to consolidate the number of rules [9]. The final decision table rule set consists of 51 rules.

Decision Tree Representation

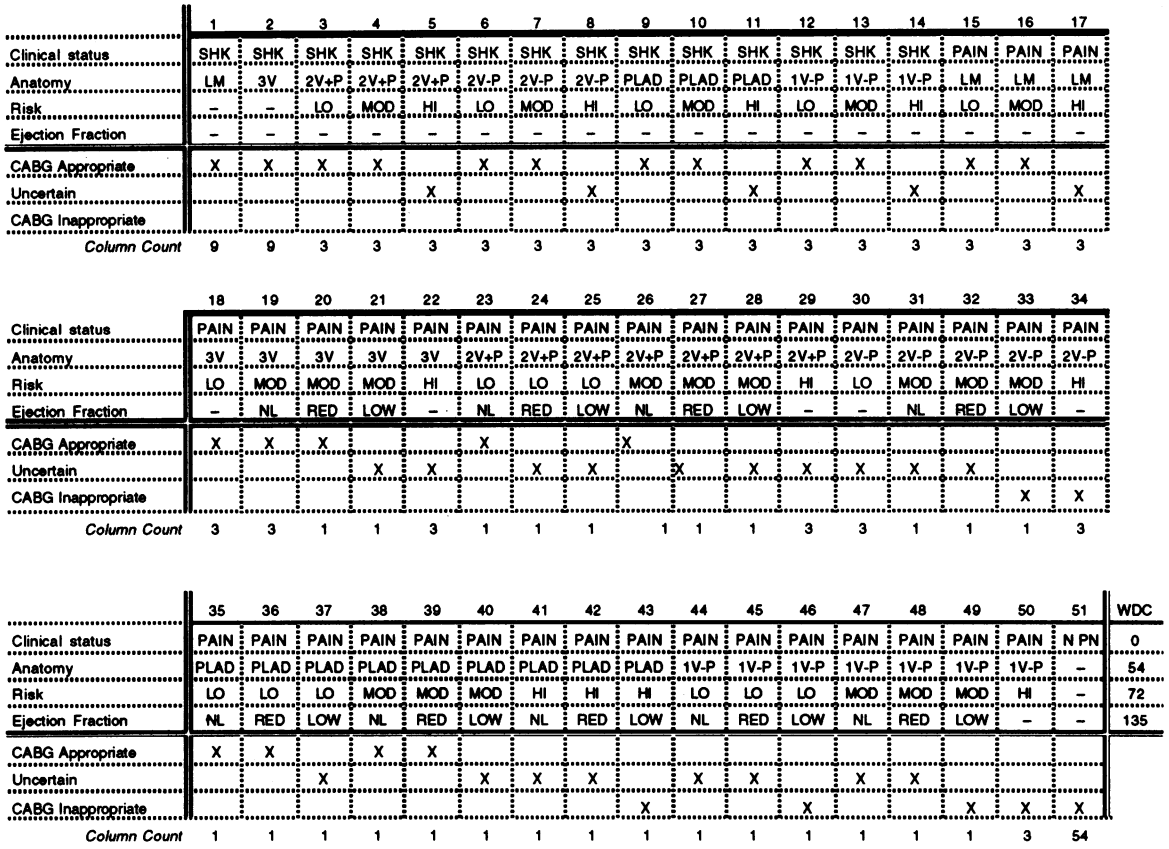
Weighted dash counts are calculated for each condition row as described above. No secondary sorting is required since the WDCs for each condition differ. The rows are sorted in order of ascending WDC. This arrangement indicates that clinical status is the most critical decision variable, followed by anatomic distribution of disease. Surgical risk is more often relevant to the decision to perform CABG than is ejection fraction.

The decision table columns are sorted as described above. The result is the decision table shown in Figure 1.

Narrative Guideline Representation

Examination of the sorted decision table facilitates generation of abstractions; it becomes possible to see the forest instead of just the trees. The WDC of the clinical status variable is 0; therefore, recommendations may be coarsely divided into 3 categories based on clinical status—cardiogenic shock (SHK), continuing pain (PAIN), and asymptomatic (N PN). For each of these three major categories, the combinations of the remaining variables that lead to a determination of CABG being appropriate or inappropriate are identified; any exceptions are noted. The result is the following set of narrative statements:

1. Patient is in cardiogenic shock
   CABG is **appropriate** for all patients **except** high risk patients with single-vessel or two-vessel disease, for whom it is **uncertain**.
2. Asymptomatic patients
   CABG is **inappropriate** for all patients who are asymptomatic.
3. Patients with uncontrolled, continuing pain
   a) Left Main Disease - CABG is **appropriate** for all patients except those in the high risk category , for whom it is **uncertain**.
   b) 3-Vessel Disease - CABG is **appropriate** for all patients except those with high risk or



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Clinical status	SHK	SHK	SHK	SHK	SHK	SHK	SHK	SHK	SHK	SHK	SHK	SHK	SHK	SHK	PAIN	PAIN	PAIN
Anatomy	LM	3V	2V+P	2V+P	2V+P	2V-P	2V-P	2V-P	PLAD	PLAD	PLAD	1V-P	1V-P	1V-P	LM	LM	LM
Risk	–	–	LO	MOD	HI	LO	MOD	HI	LO	MOD	HI	LO	MOD	HI	LO	MOD	HI
Ejection Fraction	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CABG Appropriate	X	X	X	X		X	X		X	X		X	X		X	X	
Uncertain					X			X			X			X			X
CABG Inappropriate																	
Column Count	9	9	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
Clinical status	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN
Anatomy	3V	3V	3V	3V	3V	2V+P	2V+P	2V+P	2V+P	2V+P	2V+P	2V+P	2V-P	2V-P	2V-P	2V-P	2V-P
Risk	LO	MOD	MOD	MOD	HI	LO	LO	LO	MOD	MOD	MOD	HI	LO	MOD	MOD	MOD	HI
Ejection Fraction	–	NL	RED	LOW	–	NL	RED	LOW	NL	RED	LOW	–	–	NL	RED	LOW	–
CABG Appropriate	X	X	X			X			X								
Uncertain				X	X		X	X		X	X	X	X	X	X		
CABG Inappropriate																X	X
Column Count	3	3	1	1	3	1	1	1	1	1	1	3	3	1	1	1	3

	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	WDC
Clinical status	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	PAIN	N PN	0
Anatomy	PLAD	PLAD	PLAD	PLAD	PLAD	PLAD	PLAD	PLAD	PLAD	1V-P	1V-P	1V-P	1V-P	1V-P	1V-P	1V-P	–	54
Risk	LO	LO	LO	MOD	MOD	MOD	HI	HI	HI	LO	LO	LO	MOD	MOD	MOD	HI	–	72
Ejection Fraction	NL	RED	LOW	NL	RED	LOW	NL	RED	LOW	NL	RED	LOW	NL	RED	LOW	–	–	135
CABG Appropriate	X	X		X	X													
Uncertain			X			X	X	X		X	X		X	X				
CABG Inappropriate									X			X			X	X	X	
Column Count	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	54	

Figure 1. Sorted decision table representation of the appropriateness of CABG in acute myocardial infarction. Abbreviations are defined in Table 1.

low ejection fraction, for whom it is **uncertain**.

c) 2-Vessel Disease, including the Proximal Left Anterior Descending Artery (PLAD) - CABG is **appropriate** for all patients with low or moderate risk and normal ejection fraction. For others it is **uncertain**.

d) 2-Vessel Disease, excluding the PLAD - CABG is never appropriate. It is **inappropriate** if the patient is high risk or has a low ejection fraction. For all others, it is **uncertain**.

e) 1-Vessel Disease (PLAD) - CABG is **appropriate** if the patient is at low or moderate risk and has a normal or reduced ejection fraction. For all others, it is **uncertain**, except for patients who are at high risk and have a low ejection fraction, for whom it is **inappropriate**.

f) 1-Vessel Disease (not the PLAD) - CABG is never appropriate. It is **uncertain** for patients with low or moderate risk and normal or reduced ejection fraction. For all others, it is **inappropriate**.

DISCUSSION

We have shown how a comprehensive set of criteria for appropriateness of CABG can be translated into operational guidelines for clinical practice. Using decision table representation and manipulation of the knowledge contained in the RAND report, a compact narrative summary of the panel opinions can be generated.

The number of rules could be further reduced using a semantic subsumption technique [9]. For example, the concept "2-vessel disease" subsumes both "2-vessels including PLAD" and "2-vessels without PLAD involvement"; likewise "single vessel disease" subsumes both "PLAD" and "single vessel except PLAD". Following this approach, columns 3,4,6 and 7 could be combined into a single statement covering patients in shock, with 2-vessel disease who are at low or moderate risk. Subsumption was not applied to this example to better illustrate the sorting proceedure.

The Institute of Medicine distinguishes appropriateness criteria from clinical practice guidelines based on the intent of the designers [12]. Appropriateness criteria are developed for retrospective evaluation of the appropriateness of clinical decisions, not to assist in the decision-making process. However, the knowledge embodied in these review criteria can also be applied

prospectively or contemporaneously to clinical decision making. Such an action should only be performed after careful review and sanction of the final recommendations by a panel of domain experts. Translation of appropriateness criteria into guidelines is best carried out by those who will use them [13].

For purposes of consolidation and simplification the authors combined the experts' 9-level ranking into a 3-level determination of appropriate, uncertain, or inappropriate. This change in granularity is associated with some information loss, but is necessitated by the need to achieve a summary value. Nonetheless, it may not be safe to assume that the resultant "rules" accurately convey the experts' intent.

The RAND appropriateness criteria could be displayed electronically in an augmented decision table format. Information regarding the level of agreement or disagreement among the experts' ratings might be depicted using alternative colors or typestyles for each summary rating. By double-clicking on any action entry cell, the user could bring up a window that fully summarizes the expert rating for that indication, including a count of the number of panelists chosing each rank, the median score, and the mean absolute deviation from the median (Figure 2).

The optimal format for display of guideline decision aids is a matter of current research interest [12]. Currently, most guidelines are published either as narrative text or as flowcharts. A decision table can serve as a useful intermediary since it is straightforward to convert a decision table into a flowchart or, as this paper shows, into narrative form.

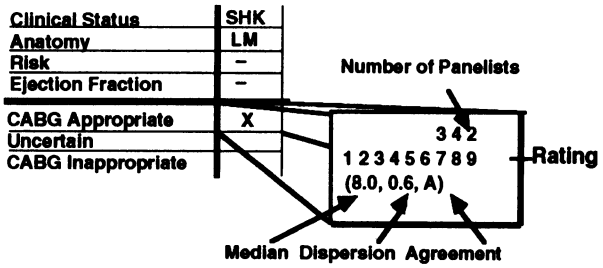


Figure 2. Augmented view of decision table. By double-clicking on a recommended action cell, the user brings up a window that contains information on the number of expert panelists who chose each rating, the median rating, a measure of the dispersion of the ratings, and a statistical indication of the level of agreement of the panelists.

Acknowledgment

This work was supported by grant LM07092 from the National Library of Medicine.

References

1. Audet A-M, Greenfield S, Field M. Medical practice guidelines: current activities and future directions. Ann Intern Med 1990;113:703-714.
2. Woolf SH. Practice guidelines: a new reality in medicine I. Recent developments. Arch Intern Med 1990;150:1811-1818.
3. Haines A, Feder G. Guidance on guidelines; writing them is easier than making them work. Brit Med J 1992;305(October 3):785-6.
4. Eddy DM. A manual for assessing health practices and designing practice policies. Philadelphia: American College of Physicians, 1992.
5. Woolf SH. Interim Manual for Clinical Practice Guideline Development. Agency for Health Care Policy and Research, 1991.
6. Park R, Fink A, Brook RH. Physician ratings of appropriate indications for six medical and surgical procedures. Am J Public Health 1986;76:766-772.
7. Leape LL, Hilborne LH, Kahan JP, et al. Coronary artery bypass graft: a literature review and ratings of appropriateness and necessity. Santa Monica, Calif. RAND, 1991.
8. Shiffman RN, Greenes RA. Use of augmented decision tables to convert probabilistic data into clinical algorithms for the diagnosis of appendicitis. In: Clayton PD, ed. Fifteenth Annual Symposium on Computer Applications in Medical Care.Washington, DC: McGraw Hill, 1991: 686-690.
9. Shiffman RN, Greenes RA. Rule set reduction using augmented decision table and semantic subsumption techniques: application to cholesterol guidelines. In: Frisse M, ed. Sixteenth Annual Symposium on Computer Applications in Medical Care. Baltimore, MD: McGraw Hill, 1992: 339-343.
10. CODASYL. A modern appraisal of decision tables. New York: Association for Computing Machinery, 1982.
11. Hurley RB. Decision Tables in Software Engineering. New York: Van Nostrand Reinhold, 1983.
12. Institute of Medicine. Guidelines for clinical practice: from development to use. Field MJ, Lohr KN, eds. Washington, DC: National Academy Press, 1992.
13. Leape LL. Practice guidelines and standards: an overview. QRB 1990;16(2):40-49.